Radio path profiles and the Fresnel zone

By Harold Kinley, C.E.T.

Establishing a highly reliable radio communications link between two fixed points often requires a line-of-sight path between the transmitter and receiver antenna, especially if the transmitter power is to be held to a minimum. For radio propagation purposes, the radius of the earth is considered to be 4/3 (1.333) times the natural radius. This longer radius produces a model of a "flatter" earth. (See Figure 1 to the right.) Thus, radio line-of-sight is approximately 15% greater than optical line-of-sight over smooth earth.

Formula 2 in the box on page 56 provides a means of calculating the maximum radio line-of-sight distance between two towers of given heights, h_1 and h_2. Suppose the height of the first tower is 100 feet, and the height of the second tower is 150 feet. The maximum allowable radio line-of-sight distance (D) between the two towers is:

$$D = \sqrt{2(100)} + \sqrt{2(150)}$$
$$= \sqrt{200} + \sqrt{300}$$
$$= 14.14 + 17.32$$
$$= 31.46 \text{ miles}$$

continued on page 56

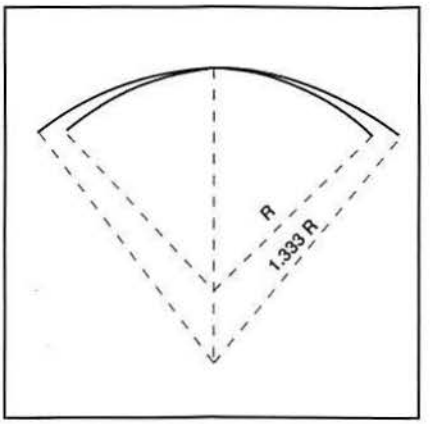

Figure 1. This graph shows how increasing the effective radius of the earth produces a 'flatter' earth, resulting in a longer line-of-sight distance between two points of given distance separation and antenna heights.

Kinley is a certified electronics technician with the South Carolina Forestry Commission, Spartanburg, SC. He is the author of *Standard Radio Communications Manual: With Instrumentation and Testing Techniques*, Prentice-Hall, 1985.

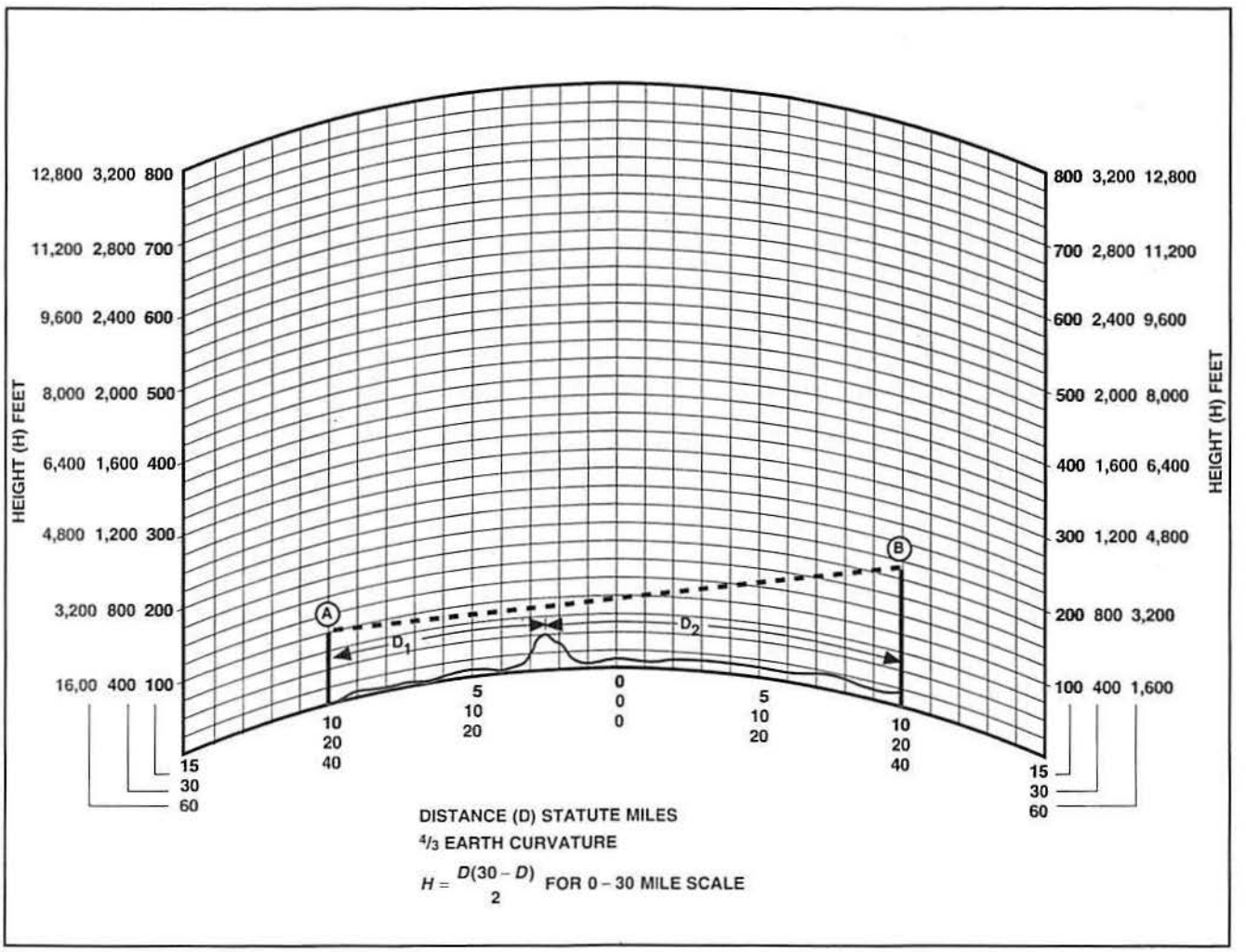

Figure 2. The 4/3 earth curvature profile paper is used to check for proper line-of-sight clearance between antenna towers A and B. Although a direct line-of-sight path exists, the large hill probably would prevent sufficient Fresnel zone clearance for free-space propagation loss. *Profile paper courtesy of Ericsson GE Mobile Communications.*

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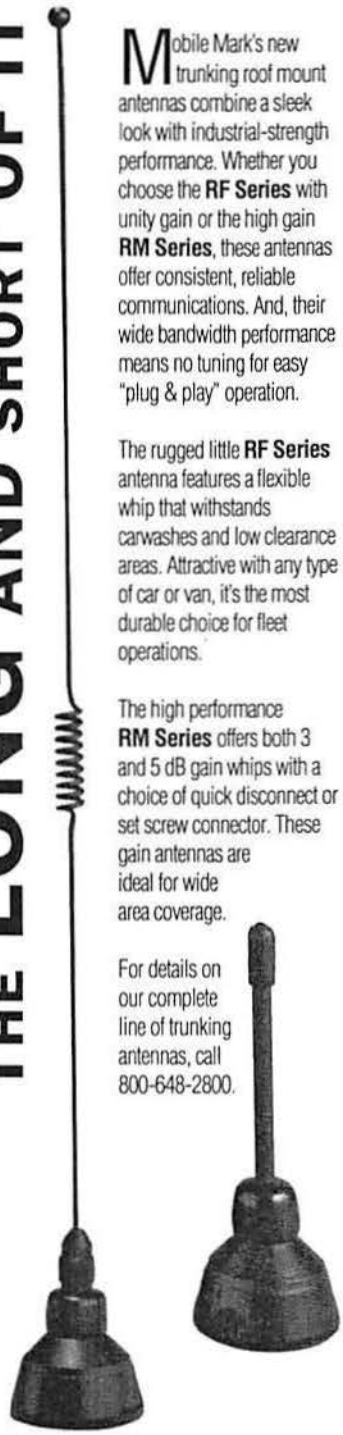

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Technically speaking

continued from page 8

1) $D = \sqrt{2h}$

where D = line of sight distance to horizon in miles
h = tower height in feet

2) $D = \sqrt{2h_1} + \sqrt{2h_2}$

where D = line of sight distance between two towers in miles
h_1 = height of first tower in feet
h_2 = height of second tower in feet

3) $r_1 = 31.67\sqrt{\frac{\lambda D_1 D_2}{D_1 + D_2}}$

where r_1 = first Fresnel zone in meters
λ = wavelength in meters
D_1 = shorter distance in kilometers
D_2 = longer distance in kilometers

4) $r_1 = 548.33\sqrt{\frac{D_1 D_2}{F(D_1 + D_2)}}$

where r_1 = first Fresnel zone in meters
F = frequency in MHz
D_1 = shorter distance in kilometers
D_2 = longer distance in kilometers

5) $r_1 = 2,280\sqrt{\frac{D_1 D_2}{F(D_1 + D_2)}}$

where r_1 = first Fresnel zone in meters
F = frequency in MHz
D_1 = shorter distance in miles
D_2 = longer distance in miles

6) $L = 20\log D + 20\log F + 32.3$

where L = free-space path loss in decibels between halfwave dipoles
D = distance in miles
F = frequency in MHz

7) $r_N = r_1\sqrt{N}$

where r_N = Nth Fresnel zone
r_1 = first Fresnel zone
N = integer (2, 3, . . .)

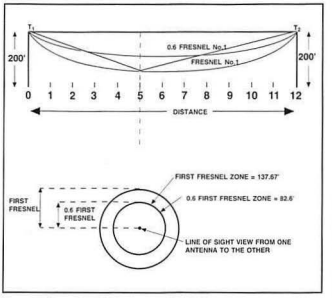
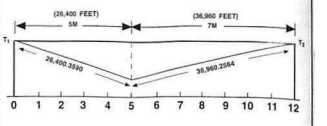


Figure 3. Towers T_1 and T_2 are separated by 12 miles. The curved lines represent the limits of the first Fresnel zone and 60% first Fresnel zone. The straight green line represents the direct path between the two antennas. The solid lines bounded by the first Fresnel zone represent the indirect path. The indirect path bounded by the first Fresnel zone is 0.5λ longer than the direct path. The first Fresnel zone completely surrounds the direct path as shown at the lower part of the figure. The actual shape of the Fresnel zone would resemble an elongated football surrounding the line-of-sight path.



$$\lambda = \frac{984.24}{F} = \frac{984.24}{800} = 1.2303 \text{ FEET}$$

$$\frac{\lambda}{2} = \frac{1.2303}{2} = 0.6152 \text{ FEET}$$

INDIRECT PATH = $c + c'$ = 26,400.3590 + 36,960.2564 = 63,360.6154 FEET

DIRECT PATH = $a + a'$ = 26,400 + 36,960 = 63,360.0000 FEET

INDIRECT PATH IS 0.615 FEET OR 0.5λ LONGER THAN DIRECT PATH

Figure 4. This drawing represents the direct and indirect path of the same towers shown in Figure 3. Line *b*, extending down from the direct path, represents the radius of the first Fresnel zone at a distance of 5 miles from tower T_1. The direct path is equal to $a + a'$. The indirect path is equal to $c + c'$, and is 0.5λ longer than the direct path.

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Formula 2 in the sidebar can be rearranged to find the required height of the second tower if the required radio line-of-sight distance D and the height of the first tower (h_1) are known. It is rearranged as follows:

$$h_2 = \frac{(D - \sqrt{2h_1})^2}{2}$$

Remember, these calculations are for radio line-of-sight over smooth earth. Unfortunately, the earth is not very smooth in many places. The profile of the earth's terrain must be taken into account when establishing radio line-of-sight communication between two fixed points.

One way of constructing a path profile is to use a topographic map to compute the various elevations between the two fixed points and then plot them on 4/3 earth curvature profile paper. (See Figure 2 on page 8.) Here, using the lowest scales, the height of tower A is 100 feet, and the height of tower B is 200 feet. The terrain profile (compiled from topographic maps) has been sketched in. Although there is a hill about 7.4 miles from tower A, there is a clear line-of-sight path between towers A and B.

Free-space attenuation

To achieve free-space attenuation (or

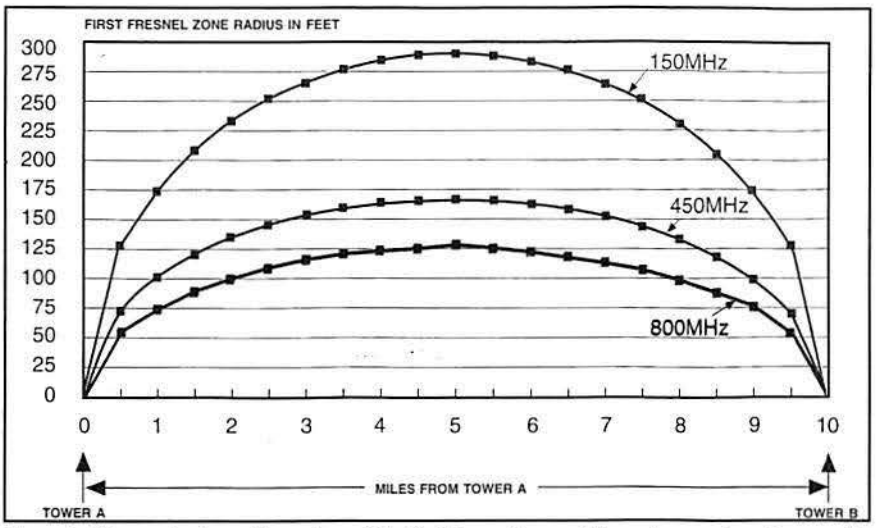

Figure 5. This graph shows the radius of the first Fresnel zone at three frequencies at any point between two towers separated by 10 miles. Notice how much smaller the first Fresnel zone radius is at 800MHz compared to 150MHz.

something close to it), an extra margin of clearance (more than radio line-of-sight) must be provided. For example, in Figure 2, even though radio line-of-sight exists between towers A and B, free-space attenuation is not achieved because of *diffraction* loss caused by the hill at distance D_1 from tower A. To achieve almost free-space attenuation between towers A and B, at least 60% of the first Fresnel zone must clear the obstruction (hill).

Fresnel zone

The Fresnel zone is best described by example. Figure 3 on page 58 shows the first Fresnel zone and 0.6 first Fresnel zone for a line-of-sight path between two antennas separated by 12 miles at a frequency of 800MHz. In practice, it is desirable to have at least 0.6 first Fresnel zone clearance to achieve almost free-space attenuation between two antennas.

In Figure 3, the first Fresnel zone radius extends 137.67 feet outward from the line-of-sight path at the five-mile point. This zone would completely encircle the line-of-sight path as shown at the bottom of Figure 3. The maximum extension of the first Fresnel zone radius would occur at the midpoint in the transmission path (at the six-mile point in the example in Figure 3). The direct path is indicated by the straight dashed line between towers T_1 and T_2. The indirect path is indicated by the two solid lines that meet at the first Fresnel zone radius. For the first Fresnel zone, the indirect path is one-half wavelength ($\lambda/2$) longer than the direct path. This is shown more clearly in Figure 4 on page 58.

Referring to Figure 4, line b is the radius of the first Fresnel zone. The indirect path ($c + c'$) is 63,360.6154 feet. The direct path ($a + a'$) is 63,360.0000 feet. Thus, the indirect path is 0.6154 feet longer than the direct path. This distance (0.6154 feet) is equal to $\lambda/2$ at 800MHz.

At any point between the two towers (T_1 and T_2), where b is the radius of the first Fresnel zone, the indirect path ($c + c'$) will always be $\lambda/2$ longer then the direct path ($a + a'$). Distances c and c' are found from the Pythagorean theorem:

$$c = \sqrt{a^2 + b^2}$$

Frequency versus Fresnel zone

As the frequency increases, the radius of the first Fresnel zone becomes smaller, thus drawing closer to the direct line-of-sight path and requiring less clearance between the direct line-of-sight path and any obstruction. This reduction is illustrated by Figure 5 above, which shows the radius of the first Fresnel zone at three frequencies (150MHz, 450MHz and 800MHz) between two antennas 10 miles apart. Notice the difference between the first Fresnel zone radius at 150MHz and 800MHz.

Computerized terrain profiles

As mentioned earlier, profile paper with $^4/_3$ earth curvature can be used to plot terrain profiles on a particular radial or azimuth between two fixed points. Even so, this requires careful interpretation of topographic maps, and many points must be plotted on the profile paper to give sufficient resolution of the profile. This can

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take up a lot of valuable time.

The alternative is to use a software package that includes terrain profile data (elevations). The software can generate a complete terrain profile graph in a short time while you take care of other business.

Figure 6 on page 64 shows a computer-generated profile path with a 0.6 first Fresnel zone radius added. The dashed lines in the figure were not generated by the program, but have been added to show that 60% of the first Fresnel zone radius at a distance of 3.5 miles (from the antenna on the left) is 151.75 feet. This figure is the same as what would result from applying Formula 5 in the equations sidebar and then multiplying the result by 0.6 to get 60% of the first Fresnel zone.

Figure 6 shows that the antenna elevations do not offer clearance of 60% first Fresnel zone between them. Therefore, the path loss will be greater than free-space path loss. If clearance of 60% first Fresnel zone is desirable, the antenna height can be increased. This change is shown in Figure 7 on page 64 where the antenna height is 1,000 feet above mean-sea-level as compared to 910 feet in Figure 6. The result is a good clearance of 60% first Fresnel zone, which will result in minimal diffraction loss from the obstruction and which will yield almost free-space path loss between the two points.

If the operating frequency were 800MHz instead of 160MHz, the clearance would be 60% first Fresnel zone without raising the antenna height. (See Figure 8 on page 64.) Notice that 60% first Fresnel zone in Figure 8 is much smaller in radius than for the 160MHz 60% first Fresnel zone shown in Figure 6.

Figure 9 on page 64 shows a 50-mile path with the $^4/_3$ earth curvature drawn by computer. Note the considerable mid-earth bulge at the midway point on the path. Even if the terrain were extremely smooth, considerable antenna heights would be required to overcome the mid-earth bulge.

Even when line-of-sight paths are established with proper Fresnel zone clearance, problems can occur that yield results much worse than free-space propagation conditions.

Even when line-of-sight paths are established with proper Fresnel zone clearance, problems can occur that yield results much worse than free-space propagation conditions. Figure 10 on page 66 depicts a situation described to me by George Weimer of Trott Communications Group, Irving, TX. In the San Francisco area, under normal weather conditions a good, clear, line-of-sight path exists between the antennas in the example. During a temperature inversion, a thick fog layer forms and reflects radio waves (as shown by the dashed lines), resulting in a significant increase in the path loss between the two antennas.

The solution is to allow enough *fade margin* in the design to cover such anomalies. Too much built-in fade margin drives up the cost, whereas too little may severely reduce the path reliability, causing

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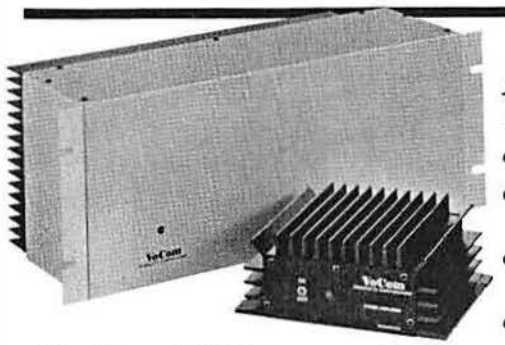

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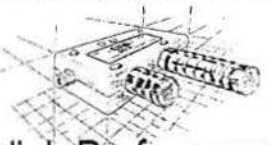

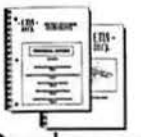

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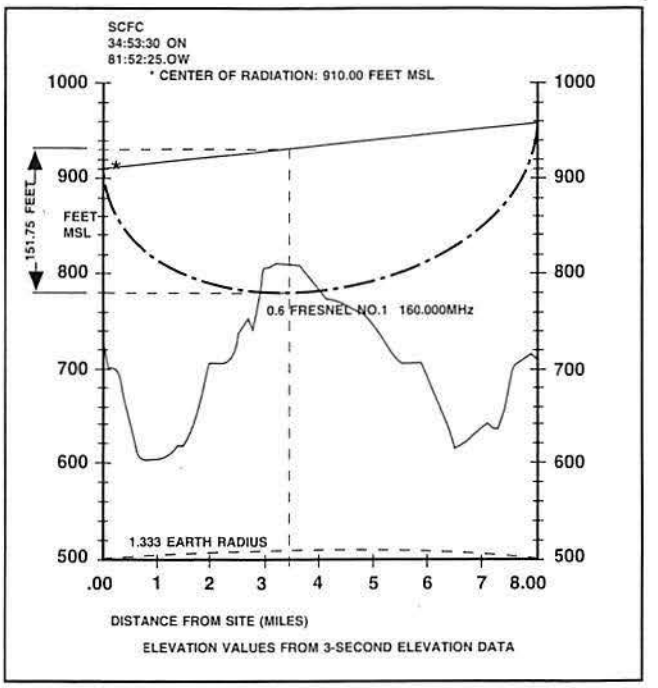

Figure 6. This terrain profile graph shows that a line-of-sight path exists between the tower on left and tower on right. Even so, at 160MHz, the path does not include 60% clearance of the first Fresnel zone. This graph was plotted with SoftWright's terrain analysis package (TAP) software.)

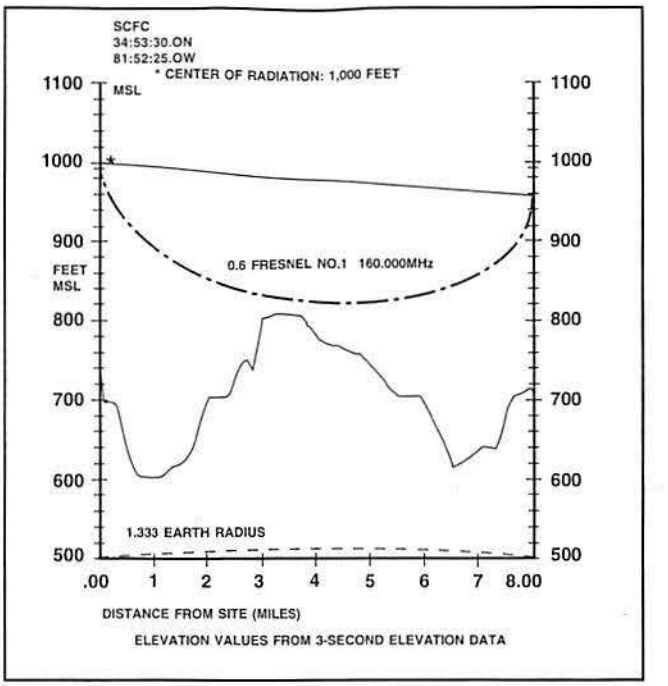

Figure 7. The tower on the left has been raised by 90 feet (compared to the same tower in Figure 6) to achieve more than 60% first Fresnel zone clearance over the obstruction 3.5 miles away. This graph was plotted with TAP software.

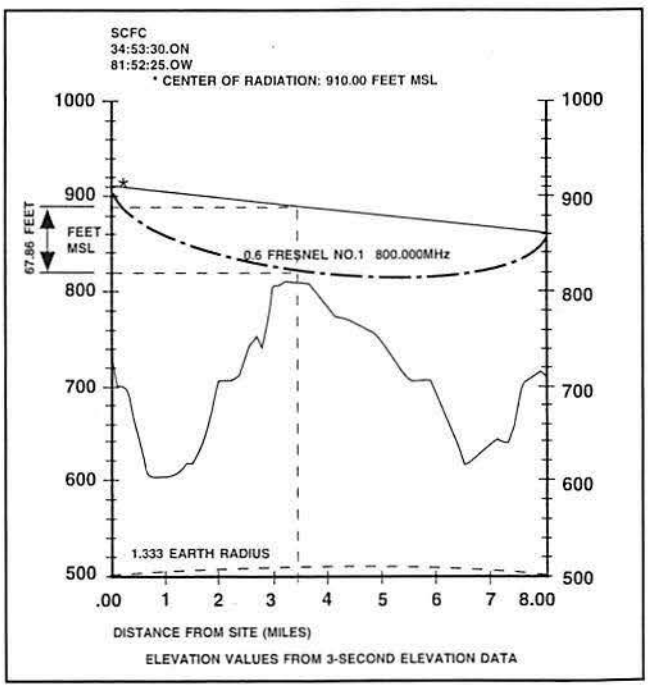

Figure 8. This terrain profile graph compares an 800MHz Fresnel zone and a 160MHz Fresnel zone. Note from Figure 7 that the left tower had to be 1,000 feet above mean sea level to achieve 60% first Fresnel zone clearance. Here, at 800MHz, 60% first Fresnel zone clearance is achieved with a tower height of 910 feet above mean sea level. The drawback is that the free-space path loss at 800MHz is about 14dB greater than the free-space path loss at 160MHz. This graph was plotted with TAP software.

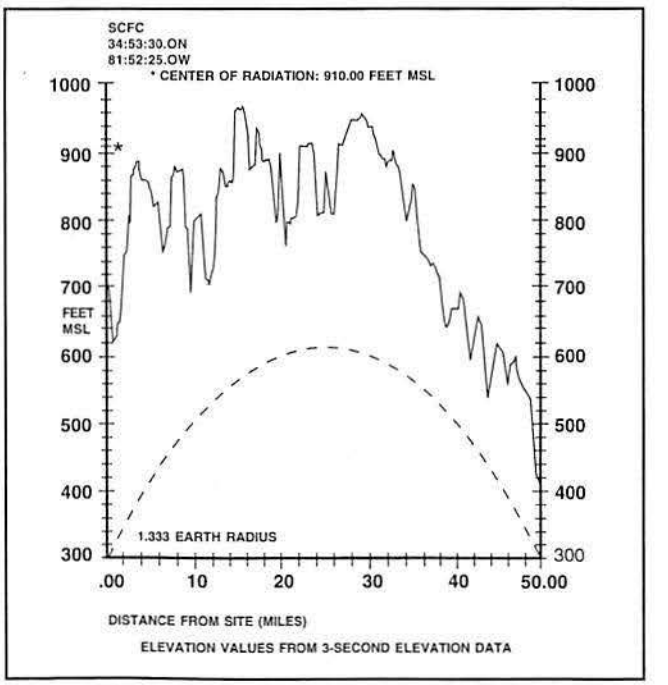

Figure 9: This terrain profile graph shows the tremendous effect of the earth's curvature over longer path distances. Tower heights greater than 300 feet would be required at each end of the path merely to clear the 'smooth earth's' curvature. Add to that the actual terrain profile, and the required tower heights for a line-of-sight path would be approximately 980 feet – 300 feet = 680 feet on each side. To achieve 60% first Fresnel zone clearance would require substantially greater tower heights. This graph was plotted with TAP software.

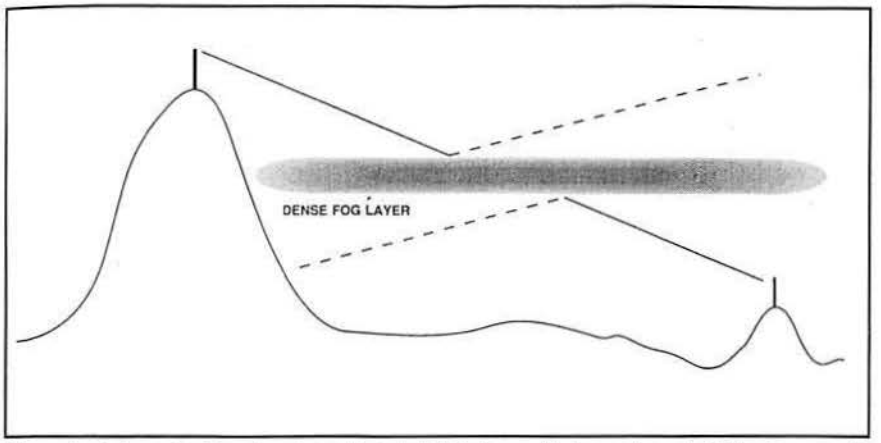

Figure 10. A dense fog layer has formed at a height between the two antenna heights. As a result, the signal from the higher antenna is reflected from the top of the layer, and the signal from the lower antenna is reflected from the bottom of the layer, resulting in significant attenuation to the path.

temporary interruptions in communications. Fade margins of 25dB to 30dB are often adequate, but there are special circumstances (such as this fog example) where a much higher fade margin might be required if the communications path is to be highly reliable. Use a common-sense approach along with your technical knowledge and data to find the "happy medium" level between overdesign and underdesign.

For those who would like computer programs that compute radio-horizon, first Fresnel zone and free-space path loss, I just happen to have some available! These programs compute the radio line-of-sight distance between two towers of specified height (smooth earth) or between a single tower of specified height and the horizon. The Fresnel programs compute the first Fresnel zone and 60% first Fresnel zone using meters, kilometers, feet, miles, wavelength and frequency. You can choose the measurement units from the menu. The free-space path loss program computes free-space path loss between two halfwave dipole antennas. Two additional programs are included to make conversions between wavelength (meters and feet) and frequency in megahertz as well as conversions between kilometers, miles, meters and feet—five programs in all.

These programs are for IBM-compatible computers running MS-DOS and are available on a single floppy diskette. Write to the author at 204 Tanglewylde Drive, Spartanburg, SC 29301-2949. Specify 5¼" or 3½" floppy. The cost is $10 for either size diskette plus $2.50 for shipping and handling.

Special thanks to Mike Wiebe of SoftWright for providing assistance with the terrain analysis profiles and to George Weimer of Trott Communications Group for answering specific questions. *Stay tuned!*

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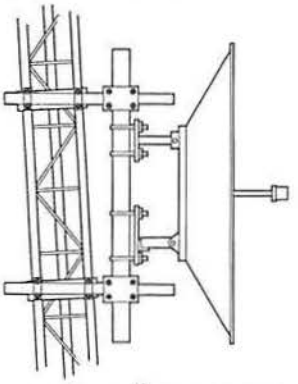

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